CHAPTER 4 - TIME OF CONCENTRATION

FIGURES

TABLES

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Introduction

The time of concentration is the time it takes for runoff to travel from the hydraulically most distant part of the watershed to its outlet. The time of concentration is usually computed by determining the water travel time through the watershed. The time of concentration determines the shape of the runoff hydrograph and can greatly affect the peak rate of flow from a watershed. Thus, it is extremely important to compute the time of concentration as accurately as possible. If, on a particular job, extra effort is to be made in developing accurate hydrology, the emphasis should be on the time of concentration.

The extent of urbanization and stream modification affects the travel time of water through the watershed. The travel time for overland flow in an urban area consists of the time it takes water to travel from the uppermost part of the watershed to a defined channel or inlet of the storm sewer system. This type of flow is significant in very small watersheds because a high proportion of travel time is due to overland flow.

Overland flow, storm sewer or road gutter flow, and channel flow are the three phases of direct flow used in computing the travel time.

Office Observations

Many times it is impractical or impossible to obtain all the desired information from the field for preliminary design computations. Photographs, soils maps and U.S. Geological Survey quadrangles are very valuable tools in determining the time of concentration for a particular watershed. With the use of these tools and a knowledge of the watershed characteristics, a reliable time of concentration can be determined.

Field Observations

At the time field surveys to obtain channel data are made, there is a definite need to observe the channel system and note items that may affect channel velocities. Observations such as the type of soil materials in the banks and bottoms of the channel, an estimate of Manning's roughness coefficient; the apparent stability or lack of stability of the channel; indications of debris flows as evidenced by deposition of coarse sediments adjacent to channels; and size of deposited materials are significant in estimating channel velocities.

Indications of channel stability can also be used to bracket the range of velocities that normally occur in that particular stream channel. It is important to note where high sediment concentrations and areas of stream erosion exist. All these factors help in determining the velocities present in the channel for a particular reach.

This manual describes a method for estimating the roughness coefficinet "n" for use in hydraulic computations associated with natural streams, floodways and similar streams. The procedure proposed applies to the estimation of "n" in Manning's formula. This formula is now widely used, it is simpler to apply than other widely recognized formulas and has been shown to be reliable.

Manning's formula is empirical. The roughness coefficient "n" is used to quantitatively express the degree of retardation of flow. The value of "n" indicates not only the roughness of the sides and bottom of the channel, but also all other types of irregularities of the channel and profile. In short, "n" is used to indicate that net effect of all factors causing retardation of flow in a reach of channel under consideration.

There seems to have developed a tendency to regard the selection of "n" for natural channels as either an arbitrary or an intuitive process. This probably results from the rather cursory treatment of the roughness coefficient in most of the more widely used hydraulic textbooks and handbooks. The fact is that the estimation of "n" requires the exercise of critical judgment in the evaluation of the primary factors affecting "n". These factors are: irregularity of the surfaces of the channel sides and bottom; variations in shape and size of cross sections; obstructions; vegetation; meandering of the channel.

The need for realistic estimates of "n" justifies the adoption of a systematic procedure for making the estimates. This procedure was adopted from "Guide for Selecting Roughness Coefficient "n" Values for Channels", USDA, SCS - Dec. 1963.

<u>Procedure for estimating "n"</u>. The general procedure for estimating "n" involves; first, the selection of a basic value of "n" for a straight, uniform, smooth channel in the natural materials involved; then, through critical consideration of the factors listed above, the selection of a modifying value associated with each factor. The modifying values are added to the basic value to obtain "n" for the channel under consideration.

In the selection of the modifying values associated with the 5 primary factors it is important that each factor be examined and considered independently. In considering each factor, it should be kept in mind that "n" represents a quantitative expression of retardation of flow. Turbulence of flow can, in a sense, be visualized as a measure or indicator of retardance. Therefore, in each case, more critical judgment may be exercised if it is recognized that as conditions associated with any factor change so as to induce greater turbulence, there should be an increase in the modifying value. A discussion and tabulated guide to the selection of modifying values for each factor is given under the following procedural steps.

<u>1st step</u>. Selection of basis "n" value. This step requires the selection of a basic "n" value for a straight, uniform, smooth channel in the natural materials involved. The selection involves consideration of what may be regarded as a hypothetical channel. The conditions of straight alignment, uniform cross section, and smooth side and bottom surfaces without vegetation should be kept in mind. Thus the basic "n" will be visualized as varying only with the materials forming the sides and bottom of the channel. The minimum values of "n" shown by reported test results for the best channels in earth are in the range from 0.016 to 0.018. Practical limitations associated with maintaining smooth and uniform channels in earth for any appreciable period indicate that 0.02 is a realistic basic "n". The basic "n", as it is intended for use in this procedure, for natural or excavated channels, may be selected from the table below. Where the bottom and sides of a channel are of different materials this fact may be recognized in selecting the basic "n".

Character of channel	Basic "n"
Channels in earth	0.02
Channels cut into rock	0.025
Channels in fine gravel	0.024
Channels in coarse gravel	0.028

2nd step. Selection of modifying value for surface irregularity. The selection is to be based on the degree of roughness or irregularity of the surfaces of channel sides and bottom. Consider the actual surface irregularity; first, in relation to the degree of surface smoothness obtainable with the natural materials involved, and second, in relation to the depths of flow under consideration. Actual surface irregularity comparable to the best surface to be expected of the natural materials involved calls for a modifying value of zero. Higher degrees of irregularity induce turbulence and call for increased modifying values. The table below may be used as a guide to the selection.

Degree of irregularity	Surfaces comparable to	Modifying value
Smooth	The best obtainable for the materials involved.	0.000
Minor	Good dredged channels; slightly eroded or scoured side slopes of canals or drainage channels.	0.005
Moderate	Fair to poor dredged channels; moderately sloughed or eroded side slopes of canals or drainage Channels.	0.010
Severe	Badly sloughed banks of natural channels; badly eroded or sloughed sides of canals or drainage channels; unshaped, jagged and irregular surfaces of channels excavated in rock	0.020

3rd step. Selection of modifying value for variations in shape and size of cross sections. In considering changes in size of cross sections judge the approximate magnitude of increase and decrease in successive cross sections as compared to the average. Changes of considerable magnitude, if they are gradual and uniform, do not cause significant turbulence. The greater turbulence is associated with alternating large and small sections where the changes are abrupt. The degree of effect of size changes may be best visualized by considering it as depending primarily on the frequency with which large and small sections alternate and secondarily on the magnitude of the changes.

In the case of shape variations, consider the degree to which the changes cause the greatest depth of flow to move from side to side of the channel. Shape changes causing the greatest turbulence are those for which shifts of the main flow from side to side occur in distances short enough to produce eddies and upstream currents in the shallower portions of those sections where the maximum depth of flow is near either side. Selection of modifying values may be based on the following guide:

Character of variations in size and shape of cross sections	Modifying value
Changes in size or shape occuring gradually	0.000
Large and small sections alternating occasionally or shape changes causing occasional shifting of main flow from side to side	0.005
Large and small sections alternating frequently or shape changes causing frequent shifting of main flow from side to side	0.010 to 0.015

4th step. Selection of modifying value for obstructions. The selection is to be based on the presence and characteristics of obstructions such as debris deposits, stumps, exposed roots, boulders, fallen and lodged logs. Care should be taken that conditions considered in other steps are not re-evaluated or double-counted by this step.

In judging the relative effect of obstructions, consider: the degree to which the obstructions occupy or reduce the average cross sectional area at various stages; the character of obstructions, (sharp-edged or angular objects induce greater turbulence than curved, smooth-surfaced objects); the position and spacing of obstructions transversely and longitudinally in the reach under consideration. The following table may be used as a guide to the selection.

Relative effect of obstructions	Modifying value
Negligible	0.000
Minor	0.010 to 0.015
Appreciable	0.020 to 0.030
Severe	0.040 to 0.060

5th step. Selection of modifying value for vegetation. The retarding effect of vegetation is probably due primarily to the turbulence induced as the water flows around and between the limbs, stems and foliage, and secondarily to reduction in cross section. As depth and velocity increase, the force of the flowing water tends to bend the vegetation. Therefore, the ability of vegetation to cause turbulence is partly related to its resistance to bending force. Furthermore, the amount and character of foliage; that is, the growing season condition versus dormant season condition is important. In judging the retarding effect of vegetation, critical consideration should be given to the following: the height in relation to depth of flow; the capacity to resist bending; the degree to which the cross section is occupied or blocked out; the transverse and longitudinal distribution of vegetation of different types, densities and heights in the reach under consideration. The following table may be used as a guide to the selection:

Vegetation and flow conditions comparable to:	Degree of effect on "n"	Range in modifying value
Dense growths of flexible turf grasses or weeds, of which Bermuda and blue grasses are examples, where the average depth of flow is 2 to 3 times the height of vegetation.	Low	0.005 to 0.010
Supple seeding tree switches such as willow, cottonwood or salt cedar where the average depth of flow is 3 to 4 times the height of the vegetation.		
Turf grasses where the average depth of flow is 1 to 2 times the height of vegetation.		
Stemmy grasses, weeds or tree seedlings with moderate cover where the average depth of flow is 2 to 3 times the height of vegetation.	Medium	0.010 to 0.025
Brushy growths, moderately dense, similar to willows 1 to 2 years old, dormant season, along side slopes of channel with no significant vegetation along the channel bottom, where the hydraulic radius is greater than 2 feet.		
Turf grasses where the average depth of flow is about equal to the height of vegetation.		
Dormant season, willow or cottonwood trees 8 to 10 years old, intergrown with some weeds and brush, none of the vegetation in foliage, where the hydraulic radius is greater than 2 feet.	High	0.025 to 0.050
Growing season, bushy willows about 1 year old intergrown with some weeds in full foliage along side slopes, no significant vegetation along channel bottom, where hydraulic radius is greater than 2 feet.		

Turf grasses where the average depth of flow is less than one half the height of vegetation.		
Growing season, bushy willows about 1 year old, intergrown with weeds in full foliage along side slopes; dense growth of cattails along channel bottom; any value of hydraulic radius up to 10 or 15 feet.	Very high	0.050 to 0.100
Growing season; trees intergrown with weeds and brush, all in full foliage; any value of hydraulic radius up to 10 or 15 feet.		

6th step. Determination of the modifying value for meandering of channel. The modifying value for meandering may be estimated as follows: Add the basic "n" for Step 1 and the modifying values of Steps 2 through 5 to obtain the subtotal of "n_s".

Let ℓ_s = the straight length of the reach under consideration.

ℓ_m = the meander length of the channel in the reach.

Compute modifying value for meandering in accordance with the following table.

Ratio ℓ_m/ℓ_s	Degree of meandering	Modifying value
1.0 to 1.2	Minor	0.000
1.2 to 1.5	Appreciable	0.15 n_s
1.5 and greater	Severe	0.30 n_s

Where lengths for computing the approximate value of ℓ_m/ℓ_s are not readily obtainable the degree of meandering can usually be judged reasonably well.

7th step. Computation of "n" for the reach. The value of "n" for the reach is obtained by adding the values determined in Steps 1 through 6. An illustration of the estimation of "n" is given in Example 1.

Example 1. Estimation of "n" for a reach.

Channel: Camp Creek dredged channel near Seymour, Illinois

Description: Course straight; 661 feet long. Cross section, very little variation in shape; variation in size moderate, but changes not abrupt. Side slopes fairly regular, bottom uneven and irregular. Soil, lower part yellowish gray clay; upper part, light gray silty clay loam. Condition, side slopes covered with heavy growth of poplar trees 2 to 3 inches in diameter, large willows and climbing vines; thick growth of water weed on bottom; summer condition with vegetation in full foliage.

Average cross section approximates a trapezoid with side slopes about 1.5 to 1 and bottom width about 10 feet. At bankfull stage, average depth and surface width are about 8.5 and 40 feet respectively.

Step	Remarks	Modifying Values
1	Soil materials indicate minimum basis "n".	0.02
2	Description indicates moderate irregularity.	0.01
3	Changes in size and shape judged insignificant.	0.00
4	No obstructions indicated.	0.00
5	Description indicates very high effect of vegetation.	0.08
6	Reach described as straight.	0.00
	Total estimated "n"	0.11

Dealing with cases where both channel and flood plain flow occurs.

Work with natural streams and floodways often requires consideration of a wide range of discharges. At the higher stages both channel and overbank or flood plain flow are involved. Usually the conditions are such that the channel and flood plain will have different degrees of retardance and, therefore, different "n" values. In such cases the hydraulic computations will be improved by dividing the cross sections into parts or subdivisions having different "n" values.

The reason for and effect of subdividing cross sections is to permit the composite "n" for the reach to vary with stage above the bankfull stage. The usual practice is to divide the cross section into two parts; one subdivision being the channel portion and the other the flood plain. More than two subdivisions may be made if conditions indicate wide variations of "n". However, in view of the practical aspects of the problem, more than three subdivisions would not normally be justified.

In estimating "n" for the channel subdivision, all of the factors discussed above and all of the procedural steps would be considered. Although conditions might indicate some variation of "n" with stage in the channel, it is recommended that an average value of "n" be selected for use in the hydraulic computations for all stages.

In the case of flood plain subdivisions, the estimate of "n" would consider all factors except meandering. That is, the estimate would employ all of the procedural steps except Step 6. Flood plain "n" values will normally be somewhat greater than the channel values. Agricultural flood plain conditions are not likely to indicate an "n" less than 0.05 to 0.06. Many cases will justify values in the 0.07 to 0.09 range and cases calling for values as high as 0.15 to 0.20 may be encountered. These higher values apply primarily because of the relatively shallow depths of flow.

Time of Concentration Computation Sheet

A time of concentration computation form has been developed (Table 4-1) and can be found on page 4-15. This form can be used with either the field or office observation method. Care should be taken to develop the time of concentration as accurately as possible. Figure 4-1 should be used to estimate the velocity for overland flow and Figures 4-2 through 4-4 should be used for estimating channel flow velocities.

The steps to complete the time of concentration computation sheet are as follows:

1. Divide up the travel path from the hydraulically most distant part of the watershed to its outlet into reaches. The reaches should be broken wherever there is a major slope change or a change in the flow condition (Example - overland flow to waterway flow; waterway flow to deep open channel flow; and etc.)

2. Station this path from the top of the watershed to the outlet using a scale on an aerial photograph, soils map or a U.S. Geological Survey quadrangle and add hatch marks along the path wherever there is a major slope change or a flow condition change.

3. From this map complete the time of concentration computation sheet. List the reach, flow condition, reach length, drop and slope.

4. From Figures 4-1 through 4-4 obtain the flow velocity based on the slope and flow condition listed.

5. Determine the travel time for the reach by dividing the reach length by the velocity.

6. Add the individual reach travel times and divide by 3600 to obtain the time of concentration in hours for the entire watershed.

For a more complete discussion of the time of concentration see Chapter 15 of Section 4, "Hydrology," SCS National Engineering Handbook and Chapter 3 of "Urban Hydrology for Small Watersheds," SCS Technical Release Number 55.

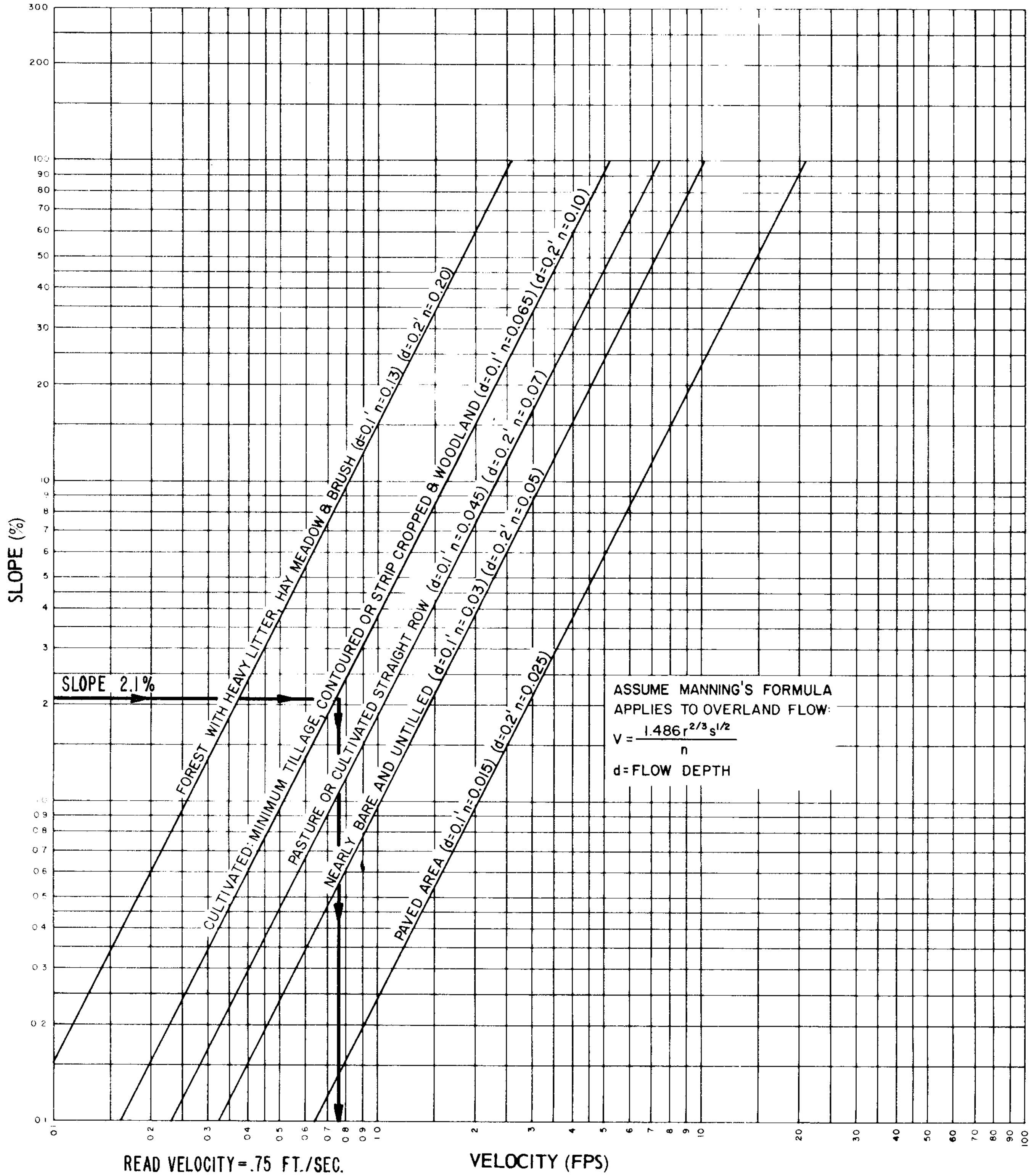


Figure 4-1
SLOPE VS. VELOCITY
OVERLAND FLOW

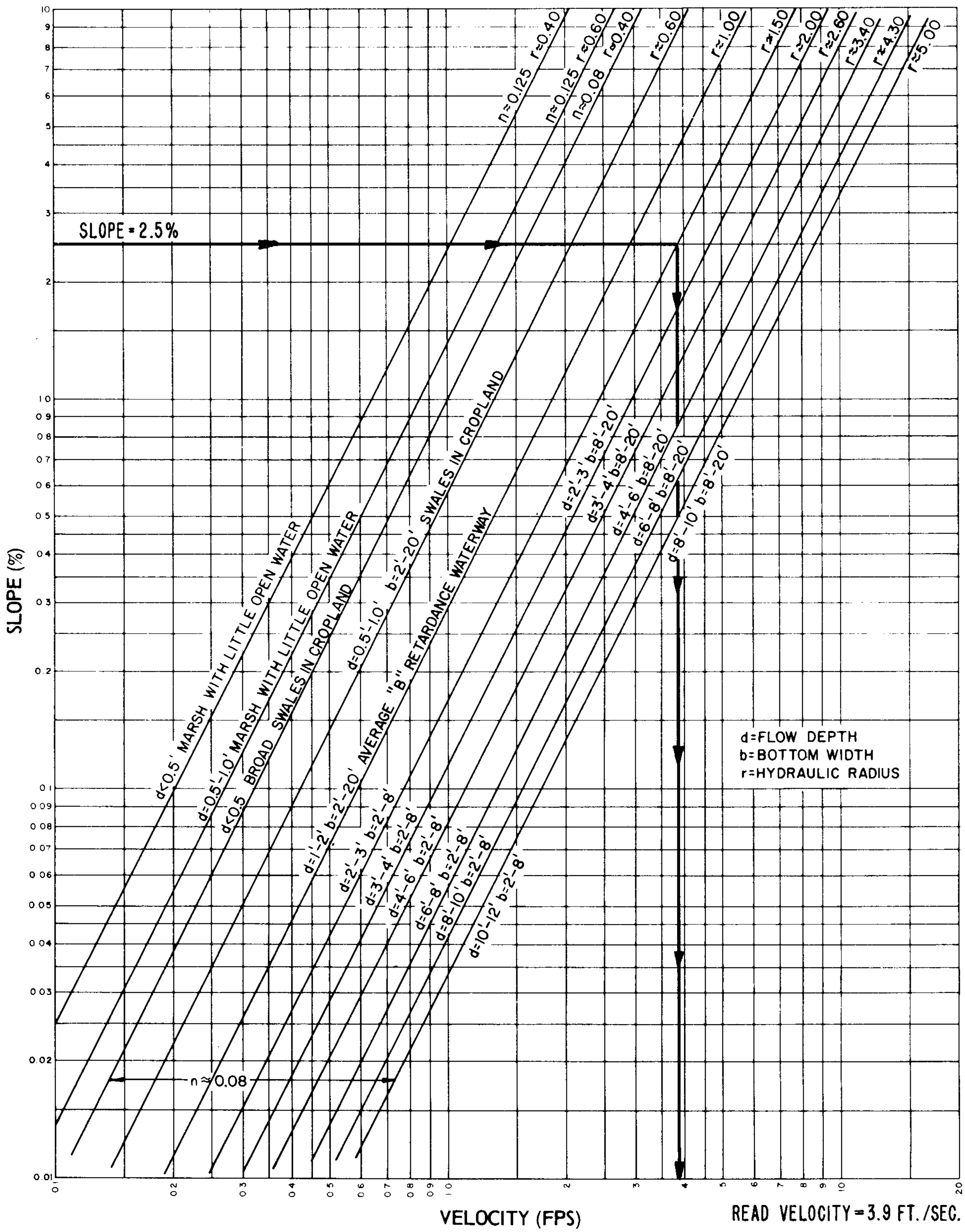


Figure 4 - 2
SLOPE VS. VELOCITY
CHANNEL PHASE
HIGH RETARDANCE CHANNELS

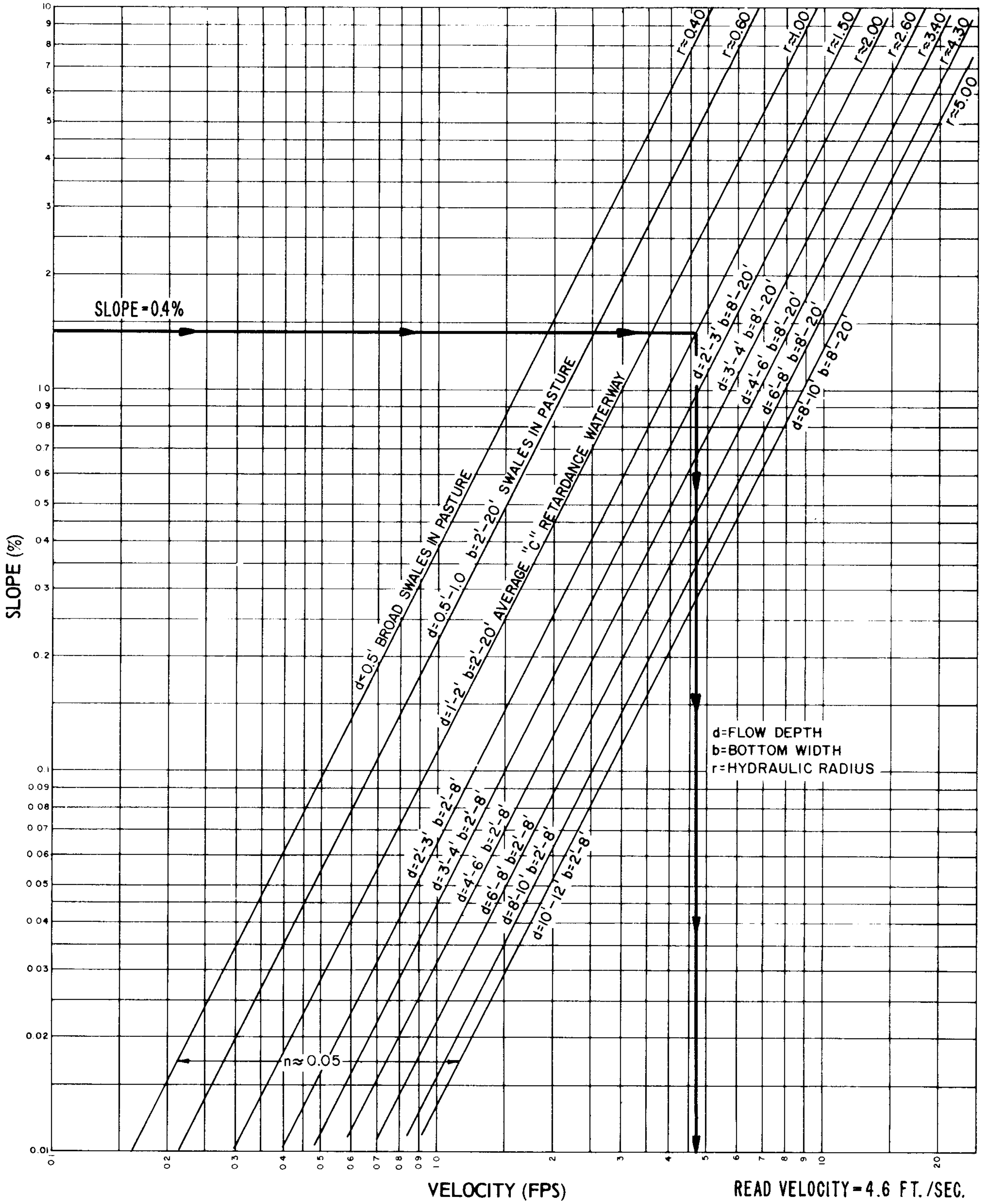


Figure 4-3
SLOPE VS. VELOCITY
CHANNEL PHASE
MEDIUM RETARDANCE CHANNELS

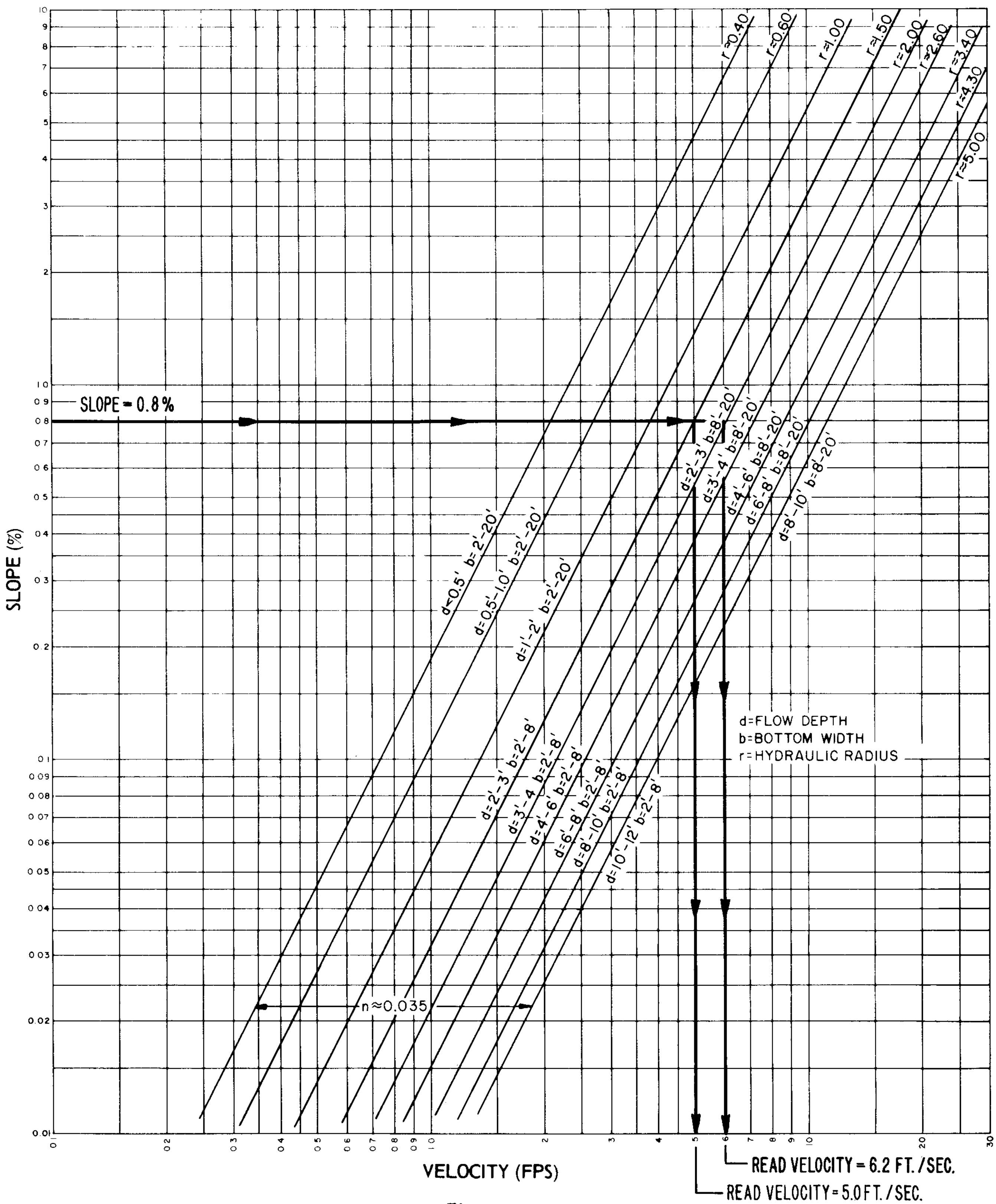
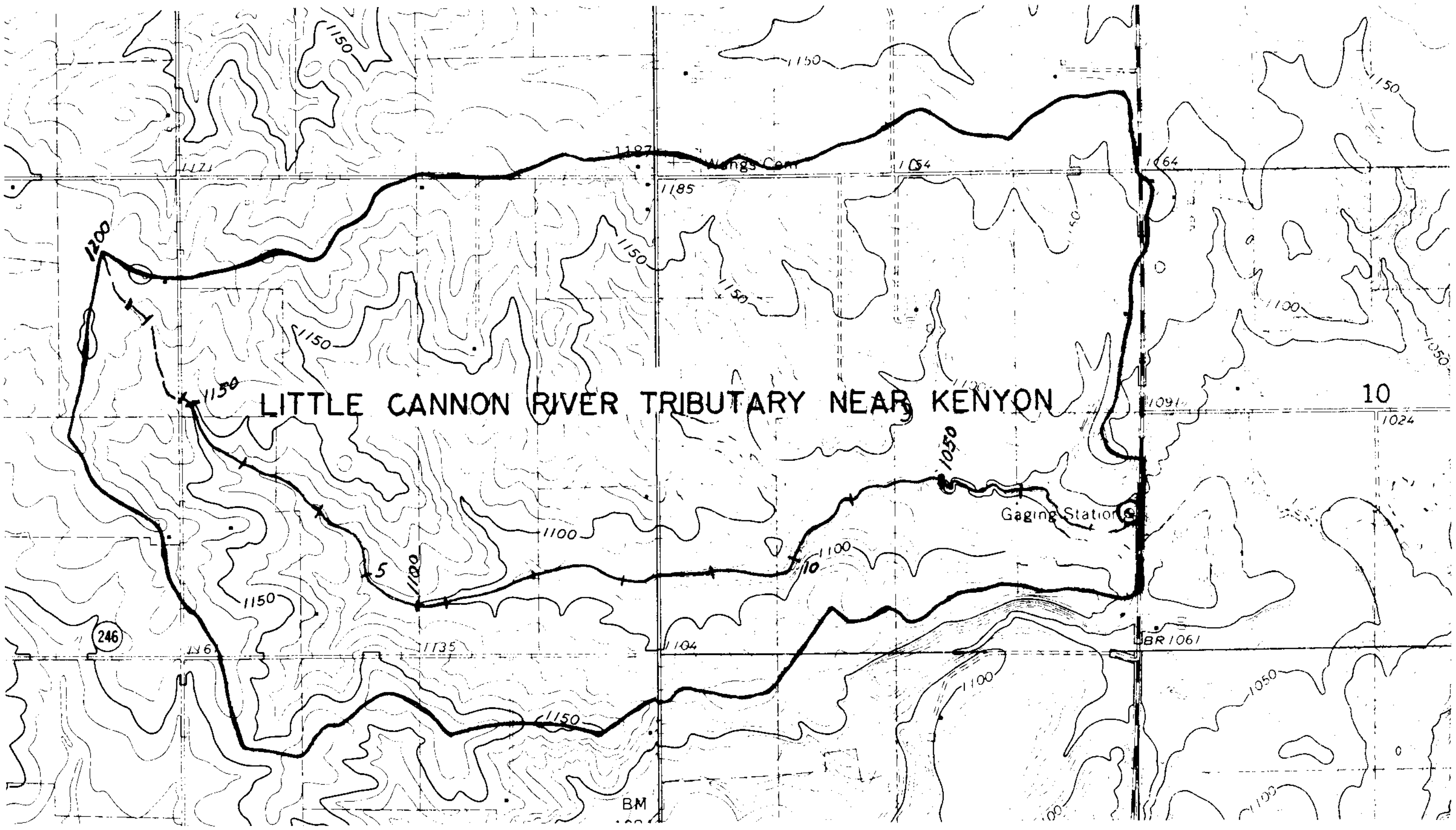


Figure 4-4
SLOPE VS. VELOCITY
CHANNEL PHASE
LOW RETARDANCE CHANNELS

FIGURE 4-5

SAMPLE WATERSHED MAP (EXAMPLE PROBLEM)



Example Problem

Given: Watershed boundary map. (See Figure 4-5.)

Determine the time of concentration to the gauging station on the Little Cannon River tributary near Kenyon.

Steps:

1. The Nerstrand quadrangle (Figure 4-5) was used to outline the watershed boundary and lay out the travel path from the hydraulically most distant part of the watershed to the gauge site. The path is laid out as a dashed line for overland and waterway flow. The path is a solid line where a channel with a constant base flow exists.

2. The path is divided into 1000 foot intervals; placing a hatch mark every 1000 feet and labeling every 5000 feet. Place a red hatch mark at every point where there is a major change in slope along the path.

3. The first four columns of the time of concentration computation sheet are then filled out using the developed map.

   a. Overland flow exists for the upper 700 feet (cultivated land).

   b. Waterway flow exists from Sta. 7+00 to 21+00 (depth = 2-3' bottom = 2-8').

   c. Shallow channel flow from Sta. 21+00 to 57+00 (depth = 2-3" bottom = 2-8', medium retardance).

   d. Channel flow from Sta. 57+00 to 120+00 (depth = 2-3' bottom = 2-8', low retardance).

   e. Channel flow from Sta. 120+00 to 146+00 (depth = 3-4' bottom = 2-8', low retardance).

4. The velocities are read from Figures 4-1 through 4-4 and the travel time for each reach is computed.

5. The individual travel times are totaled and divided by 3600 sec/hr to obtain the time of concentration of 1.0 hour for the entire watershed.

TABLE 4-1

TIME OF CONCENTRATION COMPUTATION SHEET

Present LAND USE
Present or Future

Watershed GAGE 5-3551 Site D. A. 1408 Acres

Computed by H.C.M. Date 12/30/75 Checked by J.T. Date 1/6/76

This watershed is located in the NERSTRAND USGS quadrangle.

1	2	3	4	5	6	7
Reach Sta. to Sta.	Flow Condition	Reach Length (Feet)	Drop (Feet)	Slope (4 ÷ 3) 100 (Percent)	Velocity (Ft./Sec.)	Travel Time (3 ÷ 6) (Seconds)
0+00 - 7+00	Overland 1/ (Cultivated)	700	15	2.1	0.75	933
7+00 - 21+00	Waterway 2/ (High Ret.)	1400	35	2.5	3.9	359
21+00 - 57+00	Shallow 3/ Channel (Medium Ret.)	3600	50	1.4	4.6	783
57+00 - 120+00	Channel 4/ (Low Ret.)	6300	50	0.8	5.0	1260
120+00 - 146+00	Channel 5/ (Low Ret.)	2600	20	0.8	6.2	419
					Total Travel Time (Sec.)	3754

Time of Concentration = $\frac{3754 \text{ Seconds}}{3600 \text{ Seconds/Hour}}$ = 1.04 Hours

Use 1.0 Hour

1/ Use Figure 4-1

2/ Use Figure 4-2

3/ Use Figure 4-3

4/ Use Figure 4-4

5/ Use Figure 4-4